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Analyses of tractive forces during the application of vacuum extraction

Erich Saling, Michael Hartung

Unit of Perinatal Medicine The Free University of Berlin,
Dept. of Obstetrics and Gynecology, Berlin (West)-Neukölln,

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Vacuum extraction dates back to the 18th century [1]. MALMSTRÖM first introduced a fully practicable vacuum extractor as an operative method of delivery about 20 years ago [2]. Vacuum extraction has since found increasing application and is considered in many countries to be as useful as forceps.

Numerous articles have been published concerning technique and clinical application of vacuum extraction. To date, however, there has been no direct research, as far as we know, about the extent of the effective tractive forces and the length of application during the extraction. Because of this lack criteria based upon subjective judgments were used to characterize a vacuum extraction. Such criteria are insufficient for objective analysis of tractive forces.

We have therefore developed a device for the recording of tractive forces in vacuum extractions as presented in the last issue of this Journal [4]. In connection with that article we are now reporting our first results.

1. Case material and methods

During the period from April 1972 to February 1973 we investigated 74 clinically indicated vacuum extractions with the above mentioned apparatus. Fig. 1 shows an example of a record. From all 74 records we have evaluated the following parameters:

a) **length of the whole operative measure**
b) **total duration of the applied forces**
c) **magnitude of the maximum tractive force**
d) **number of individual tractions**
e) **force-time-integral (FTI)**

For the measurement of the force-time-integral (FTI) the record was evaluated planimetrically by means of a transparent overlay. The planimetrically evaluated result represents the time integral of force $= \int F dt = FTI$ (force-time-integral). 1 mm^2 on the recording paper corresponds to 3.75 kpsec (= 36.78 kgm/sec) at a recording speed of 2 cm per minute.

2. Results

Tab. I presents a survey of the indications for operative delivery by vacuum extractor in our material. In more than 80% of the cases vacuum extraction was indicated by delay of second stage or acidity-increase determined by fetal blood sampling.

Tab. I. Indications for vacuum extraction.

Delay of second stage	n = 48
Acidity increase in the fetus	n = 15
Acute bradycardia with silent oscillations	n = 5
Continual tachycardia of more than 3 h duration	n = 4
Deep transverse arrest	n = 1
Maternal predisposition to seizures	n = 1
	total = 74

All were cases of vertex presentation in which the major portion of vacuum extractions was performed with the level of the fetal head at

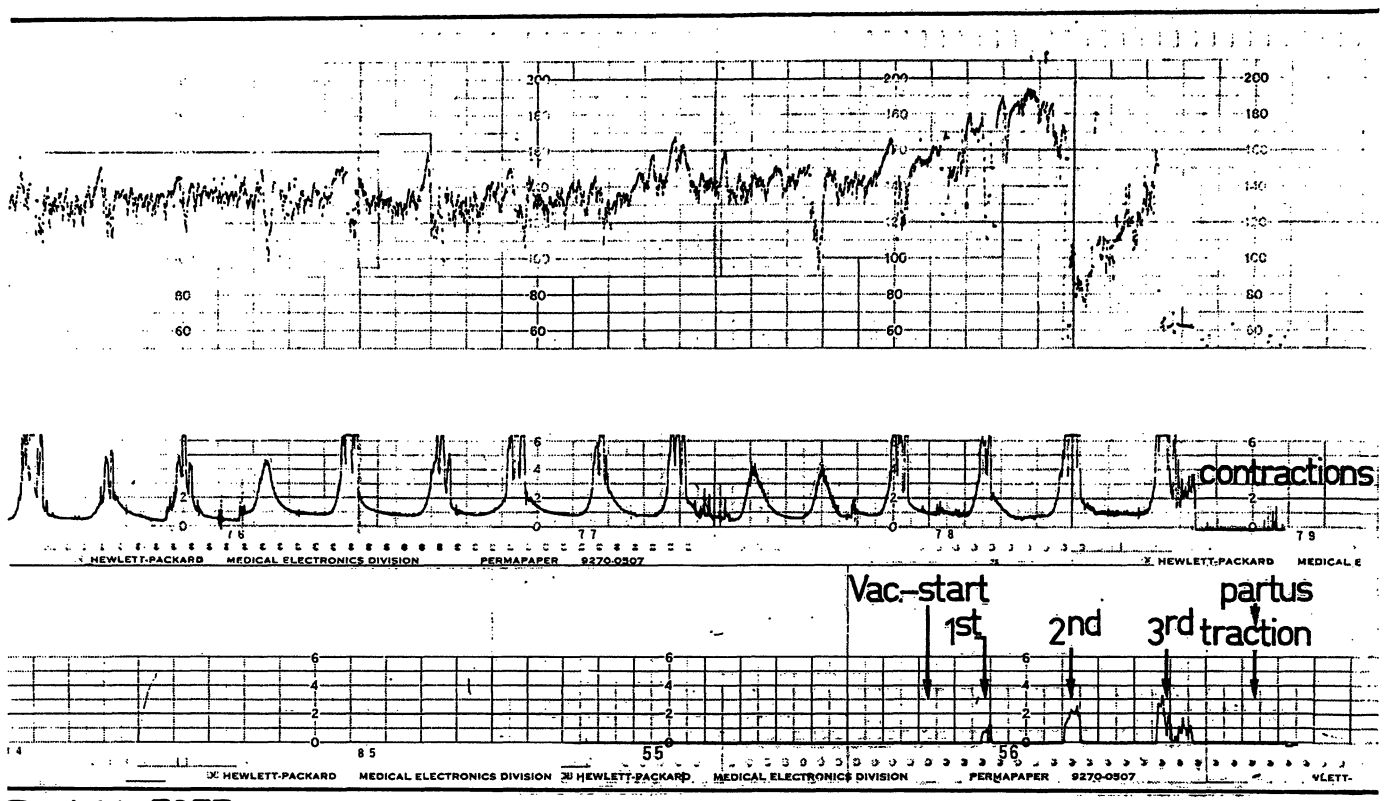

Fig. 1. Record of fetal heart rate (upper section), uterine contractions (middle section) and applied tractive forces during vacuum extraction (bottom section). One division is 5 kp, paper-speed 1 cm/min.

mid-pelvic-plane (n = 44) and pelvic floor (n = 22). In 6 cases the baby was extracted from the pelvic outlet and in only 2 cases from the pelvic inlet. We used exclusively the largest suction cup with a diameter of 6 cm.

As expected the **duration** of the vacuum extraction, the **number of individual tractions,** the **magnitude of the maximum tractive force** correlate with the **level of the fetal head** (see Tab. II). **The higher the position of the fetal head** at the beginning of the vacuum extraction **the longer the duration** of the operative measure and **the greater the number of individual tractions and the magnitude of the maximum tractive force.**

In 22 cases the maximum tractive force was ≧ 20 kp. In 10 of these 22 cases the suction cup came off. **There was no coming off of the suction cup with a maximum tractive force of less than 20 kp.** It is possible for the suction cup to come of as well in cases of less tractive force. In such cases, however, the threat of coming off can be recognized in time by the sound of entering air, so that the tractive force can be interrupted early enough. In half the cases of coming off we found depressed newborns (n = 5). The total number of depressed newborns was 11.

The force-time-integrals show similar results. **The force-time-integral increases corresponding to the level of the fetal head.** Tractions with FTI-values of less than 375 kpsec where required chiefly for extractions from the pelvic floor and the pelvic outlet. Tractions of more than 1500 kpsec were necessary only for extractions from higher pelvic levels (Fig. 2).

Tab. II. Number of tractions, maximum tractive force, length of the whole operative measure and total duration of the applied tractions.

	Number of tractions (mean)	Maximum tractive force [kp]	Length of whole operative measure [min] (mean)	Total duration of applied tractions [min] (mean)
Pelvic inlet	2.50	19.50 kp	3 min	2 min, 37 sec
Midpelvic plane	2.52	17.84 kp	2 min, 34 sec	2 min, 10 sec
Pelvic floor	1.95	14.31 kp	1 min, 19 sec	1 min, 17 sec
Pelvic outlet	1.66	10.33 kp	1 min, 10 sec	1 min, 2 sec
Maximum	8	28 kp	12 min, 30 sec	8 min, 40 sec
Minimum	1	6 kp	10 sec	10 sec

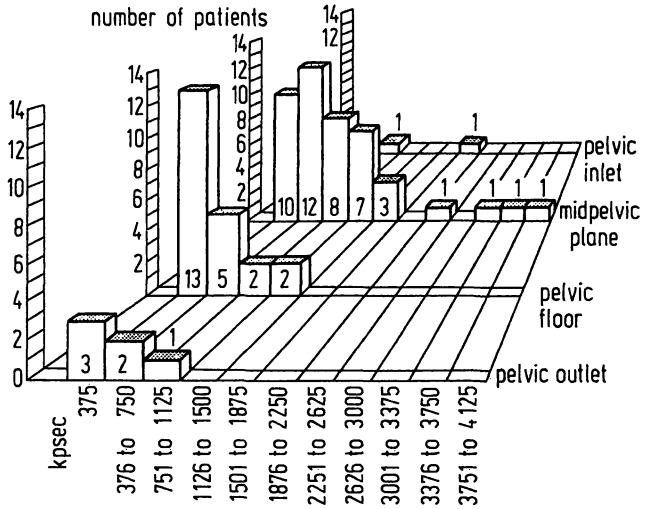

Fig. 2. Force-Time-Integrals of vacuum extractions from the various pelvic planes. Number of cases is placed within or above the columns (kpsec = kilopondsecond).

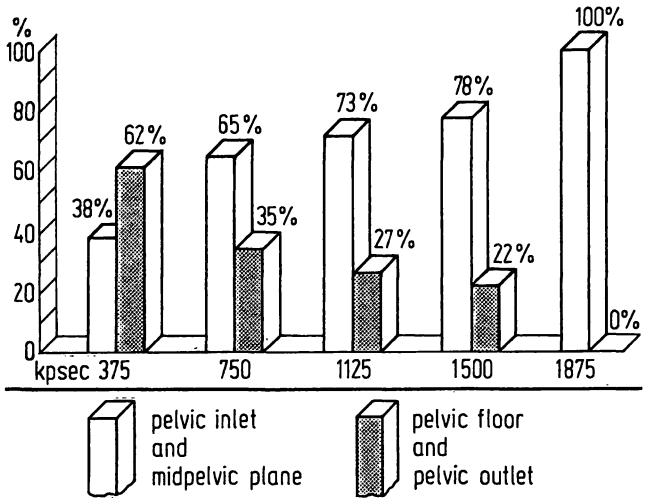

Fig. 3. Relative portions of vacuum extractions from pelvic inlet and midpelvic plane as well as from pelvic floor and pelvic outlet correlated with increasing Force-Time-Integral.

Fig. 3 represents most clearly the relationship between the extractions from the pelvic inlet and mid-pelvic plane as well as from the pelvic floor and the pelvic outlet expressed as 2 pairs on the graph. As the FTI increases, the relative portions of vacuum extractions from higher levels correspond almost inversely proportionally to those from lower levels. It follows that the **level of the fetal head is the first significant parameter for the magnitude of the FTI.**

In examining the influence of fetal size upon the forces of extraction we compared the FTI of infant groups with different birth weights at same level of the fetal head. Although this subdivision naturally results in a smaller number of cases, the evaluation shows a **clear correlation between FTI and neonatal birthweight.** As compared with the extraction of a baby weighing 2900 g from the mid-pelvic plane we found the FTI doubled at a birthweight of 3700 g (s. Tab. III).

Therefore **birthweight is the second important parameter for the magnitude of the FTI** during vacuum extraction.

Tab. III. Force-Time Integrals as a function of birthweight.

Level of the fetal head	Birthweight [g]	Mean FTI [kpsec]
Midpelvic plane	2500—2900 g	83 kpsec
	2901—3700 g	130 kpsec
	3701 g and more	178 kpsec
Pelvic floor	2500—2900 g	43 kpsec
	2901 g and more	79 kpsec

11 (14%) of the 74 newborns delivered by vacuum extraction were born in a state of depression (2 cases C I, 5 C II, 4 C III). In 5 of these 11 cases the suction cup came off (see above). The classifications of the clinical state are given in Fig. 4. We published a report of this classification system two years ago [3].

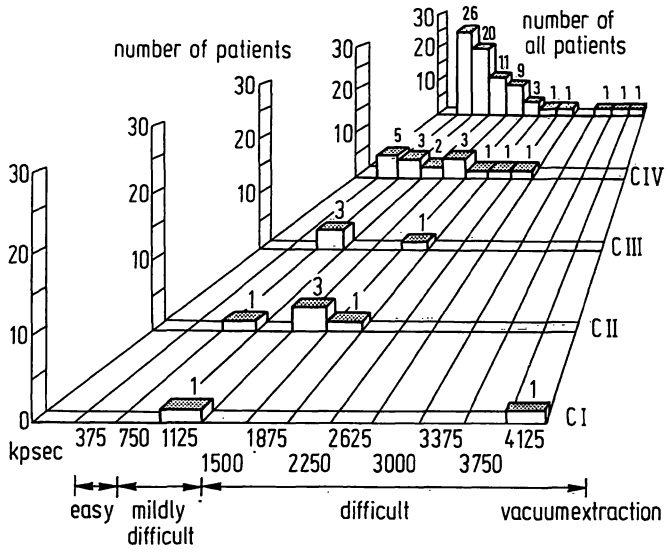

Fig. 4. Distribution-curve of all Force-Time-Integrals together with the corresponding number of newborns in a state of depression. Number of cases is placed within or above the columns. Correspondence of the scoring systems:

our system	Apgar
C IV	7—8
C III	5—6
C II	3—4
C I	0—2

It follows from Fig. 4 that **the risk of neonatal depression grows with increasing FTI.** We have therefore, for the time being arbitrarily, divided the **degree of severity of a vacuum extraction** into 3 groups:

1. **Easy vacuum** extraction up to 375 kpsec
2. **Mildly difficult** vacuum extraction 376 to 1125 kpsec
3. **Difficult** vacuum extraction 1126 and more kpsec.

In the first group there are no cases of depressed newborns, in the second 5 (16%) and in the third 6 (33%). The depression of the newborn might be a result of the vacuum extraction or could be caused by other factors; this question remains to be resolved. To settle this problem we are applying the measurement of the pH-value in the blood of the umbilical artery immediately post partum, part of our clinical routine for the past several years. The pH-values of two of these 11 newborns were normal pH $\geqq$ 7.25). In two cases there was an increase in acidity (pH 7.24—7.20), in 6 newborns a slight acidosis was found (pH 7.19—7.15) and 1 newborn had an advanced acidosis (pH 7.02).
This enables us to exclude fetal hypoxia as a cause of depression in at least four cases, so that we have to consider a **relation between the vacuum extraction and the depressed state of the newborn.**

3. Discussion of the findings

The results correspond with the common expectations of experienced clinicians. The advantage of our newly developed measuring device, however, is the **possibility** it presents **to register accurately and record objectively for the first time the magnitude and duration of tractive forces as routine procedure.**
We judge this to be an important step toward a complete collection of data concerning the birth. **The clinical assessment of a vacuum extraction,** especially its effects upon the child, **can now be based upon measurable values;** subjective miscalculations can be eliminated.
It would be premature to make far reaching clinical conclusions as a result of these findings. This problem can be first solved after further prospective research in connection with catamnestic inquiries. A great number of questions still remain open: e. g. **incidence of traumatic lesions, effects of the applied tractions upon**

the fetal heart rate, incidence of severe depression in vacuum extractions with a great FTI.

Our interest in this first analysis was centered upon researching force-time-relationships according to different parameters such as the level of the fetal head and birthweight.

Our findings to date lead to the following conclusions:

1. The FTI during the vacuum extraction clearly corresponds with the **size of fetus** and the **level of the fetal head.**
5. **Severe depression** which cannot be explained by acidosis and/or hypoxia is more **often found after vacuum extractions with a great FTI.**
3. **Coming off of the suction cup** was noted in our studies at a tractive **force of more than 20 kp.**

Summary

74 clinically indicated vacuum extractions were observed using our newly developed device for the measurement of tractive forces during vaccum extractions [4], **(Fig. 1).** The following parameters were evaluated:

length of the whole operative measure
total duration of the applied tractions
magnitude of the maximum tractive force
number of individual tractions
force-time-integral (FTI).

For extractions from the various pelvic planes the following mean values were found (pelvic inlet = PI/mid-pelvic plane = MP/pelvic floor = PF/pelvic outlet = PO):

Number of tractions: PI:2.5; MP: 2.52; PF: 1.95; PO: 1.66.

Maximum tractive force: PI: 19.50 kp; MP: 17.84 kp; PF: 14.31 kp; PO: 10.33 kp.

Length of the operative measure: PI: 3 min; MP: 2 min, 34 sec; PF: 1 min, 19 sec; PO: 1 min, 10 sec.

Total duration of the applied tractions: PI: 2 min, 37 sec; MP: 2 min, 10 sec; PF: 1 min, 17 sec; PO: 1 min, 2 sec.

All cases investigated were vertex presentations. 44 newborns were delivered from the midpelvic plane, 22 from the pelvic floor, 6 from the pelvic outlet, and 2 from pelvic inlet.

Duration of the vacuum extraction, **number of individual tractions** and **magnitude of the maximum tractive force clearly correspond with the level of the fetal head.**

In 22 cases the maximum tractive force was $\geqq$ 20 kp. **With a force of less than 20 kp no coming off of the suction cup was observed.**

The force-time-integral (FTI) of each record was evaluated planimetrically; it presents the time integral of force. In more than 80% of the cases vacuum extraction was indicated by delay of second stage or acidity-increase in the fetus. **The FTI increases in correspondence to the level of the fetal head.** Tractions with FTI-values of less than 375 kpsec were required chiefly for extractions from the pelvic outlet **(Fig. 2).** Tractions of more than 1500 kpsec were necessary only for extractions from higher pelvic levels. As the FTI increases, the relative portions of vacuum extractions from higher levels correspond almost inversely proportional to those from lower levels. **The FTI correlates to birthweight as well. The level of the fetal head and the birthweight are therefore the two most important parameters for the FTI of a vacuum extraction.**

The risk of depression grows with an increasing FTI; 11 of the 74 newborns delivered by vacuum extraction were depressed.

We have arbitrarily divided the degree of severity of a vacuum extraction into three groups:

1. **Easy vacuum extraction** up to 375 kpsec
2. **Mildly difficult vacuum extraction** 376—1125 kpsec
3. **Difficult vacuum extraction** 1126 and more kpsec.

It remains to be resolved whether the neonatal depression can be explained as a result of the vacuum extraction or other causes.

The blood pH-measurements of the umbilical artery enabled us to exclude a hypoxia as a cause of depression in at least 4 of the total 11 cases. **A connection between vacuum extraction and neonatal depression can be suspected.**

We judge this method to be an **important step toward a complete collection of data concerning the birth.** Subjective miscalculations can thus be eliminated in the future.

Keywords: Fetus, tractive force, vacuum extraction.

Zusammenfassung

Analyse der Zugkräfte bei der Vakuumextraktion

Anhand der von uns entwickelten Vakuumextraktionszugmeßausrüstung [4] **(Abb. 1)** wurden 74 klinisch indizierte Vakuumextraktionen überwacht und nach folgenden Parametern ausgewertet:

Dauer des gesamten operativen Eingriffs
Gesamtdauer der applizierten Züge
Größe der maximalen Zugkraft
Anzahl der Einzelzüge
Kraft-Zeit-Integral (KZI).

Für Extraktionen aus den verschiedenen Beckenebenen ließen sich folgende **Mittelwerte** errechnen (Becken-Eingang = BE, Becken-Mitte = BM, Becken-Boden = BB, Becken-Ausgang = BA):

Zahl der Züge: BE: 2,5; BM: 2,52; BB:1,95; BA: 1,66.

Maximale Zugkraft: BE: 19,50 kp; BM: 17,84 kp; BB: 14,31 kp; BA: 10,33 kp.

Dauer des operativen Eingriffes: BE: 3 min; BM: 2 min, 34 sec; BB: 1 min, 19 sec; BA: 1 min, 10 sec.

Gesamtdauer der applizierten Züge: BE: 2 min, 37 sec; BM: 2 min, 10 sec; BB: 1 min, 17 sec; BA: 1 min, 2 sec.

Alle untersuchten Fälle waren Schädellagen, 44 Kinder wurden aus Beckenmitte, 22 vom Beckenboden, 6 aus Beckenausgang, 2 aus Beckeneingang entwickelt.
Dauer der Vakuumextraktion, Anzahl der Einzelzüge und Größe der maximalen Zugkraft **korrelieren deutlich mit dem Höhenstand des kindlichen Kopfes.**
22mal betrug die maximale Zugkraft $\geqq$ 20 kp. **Unterhalb einer Zugkraft von 20 kp war kein Abreißen der Saugglocke zu beobachten.** Das Kraft-Zeit-Integral (KZI) eines jeden Zugmeßprotokolls wurde planimetrisch bestimmt; es repräsentiert das Zeitintegral der Kraft. In mehr als 80% der Fälle erfolgte die VE wegen Geburtsstillstandes oder einer durch Fetalblutanalysen festgestellten Aziditätssteigerung beim Feten. **Das KZI wächst in Abhängigkeit vom Höhenstand des kindlichen Kopfes.** Züge mit KZI-Werten unter 375 kpsec wurden vorwiegend zur Extraktion aus Beckenboden und Beckenausgang benötigt **(Abb. 2).** Züge mit mehr als 1500 kpsec waren nur für Extraktionen aus höheren Beckenebenen erforderlich. Mit steigendem KZI verhalten sich die relativen Anteile von Vakuumextraktionen aus höheren Ebenen im Vergleich zu denen aus niederen Ebenen nahezu umgekehrt proportional **(Abb. 3).** Das **KZI korreliert auch mit dem kindlichen Geburtsgewicht.** Der **Höhenstand des kindlichen Kopfes und das Geburtsgewicht sind somit die beiden wesentlichen Parameter für das KZI einer Vakuumextraktion.**
Das Risiko eines Depressionszustandes nimmt mit steigendem KZI zu **(Abb. 4);** 11 der 74 durch VE entwickelten Kinder wurden in einem Depressionszustand geboren.
Zur Differenzierung des Schweregrades einer Vakuumextraktion haben wir zunächst willkürlich die VE in drei Gruppen unterteilt:

1. **Leichte VE** bis 375 kpsec
2. **Mittelschwere VE** 376—1125 kpsec
3. **Schwere VE** 1126 kpsec und mehr.

Es bleibt zu klären, ob der kindliche Depressionszustand als Folge der VE anzusehen oder vielmehr durch andere Ursachen erklärbar ist. Durch die Meßergebnisse der Nabelarterienblut-pH-Werte unmittelbar post partum konnte in mindestens 4 der insgesamt 11 Fälle mit Depressionszustand eine Hypoxie als Ursache der Depression ausgeschlossen werden, so daß an Beziehungen zwischen der VE und dem kindlichen Depressionszustand gedacht werden muß. Wir halten das Zugmeßprotokoll für einen weiteren wichtigen Schritt zur Vervollständigung wichtiger, das Kind betreffender Geburtsdaten. Subjektive Fehleinschätzungen werden hiermit in Zukunft vermieden.

Schlüsselwörter: Fetus, Vakuumextraktion, Zugkräfte.

Résumé

Analyses des forces de traction durant l'application de l'extraction obstétricale

A l'aide des instruments de mesure que nous avons mis au point [4] **(Fig. 1),** nous avons observé 74 extractions obstétricales sur indication clinique en **déterminant les paramètres suivants:**

Durée de toute l'intervention opératoire
Durée totale des tractions appliquées
Grandeur de la force de traction maximale
Nombre des tractions individuelles
Intégrale force-temps (IFT).

Pour les extractions des divers détroits du bassin, on a trouvé les valeurs moyennes suivantes (détroit supérieur du bassin = PI, détroit moyen du bassin = MP, plancher pelvien = PF, détroit inférieur du bassin = PO):

Nombre des tractions: PI: 2,5; MP: 2,52; PF: 1,95; PO: 1,66.

Force de traction maximale: PI: 19,50 kp; MP: 17,84 kp; PF: 14,31 kp; PO: 10,33 kp.

Durée de l'intervention opératoire: PI: 3 min; MP: 2 min, 34 sec; PF: 1 min, 19 sec; PO: 1 min, 10 sec.

Durée totale des tractions appliquées: PI: 2 min, 37 sec; MP: 2 min, 10 sec; PF: 1 min, 17 sec; PO: 1 min, 2 sec.

Tous les cas observés présentaient une position du sommet. 44 nouveaux-nés ont été délivrés du détroit moyen du bassin, 22 du plancher pelvin, 6 du détroit inférieur du bassin et 2 du détroit supérieur du bassin.

La durée de l'extraction obstétricale, **le nombre des tractions** individuelles et **la grandeur de la force de traction maximale dépendent clairement du niveau de la tête du foetus.**

Dans 22 cas, la force de traction maximale était $\geqq$ 20 kp. **Pour une force de traction inférieure à 20 kp, on n'a observé aucun détachement de la ventouse.** L'intégrale force-temps (IFT) de chaque cas enregistré a été mesurée planimètriquement; elle représente l'intégrale temps de la force. Dans plus de 80% des cas, on a dû recourir à l'extraction obstétricale à cause d'un retard de la deuxième période d'accouchement ou d'une augmentation d'acidité chez le foetus. L'IFT augmente proportionnellement au niveau de la tête du foetus. Les tractions de valeurs IFT inférieures à 375 kpsec furent nécessitées surtout pour les extractions du détroit inférieur du bassin et du plancher pelvien **(Fig. 2)** et les tractions supérieures à 1500 kpsec seulement pour les extractions des détroits supérieurs du bassin. Pour une IFT croissante, les portions relatives des extractions des détroits supérieurs sont presqu'inversement proportionnelles à celles des détroits inférieurs **(Fig. 3). L'IFT correspond aussi au poids du nouveau-né. Le niveau de la tête** du foetus et le poids du nouveau-né constituent, en conséquence, les deux paramètres essentiels pour l'IFT d'une extraction obstétricale.

Le risque d'un état dépressif augmente avec une IFT croissante (Fig. 4); il atteignit 11 des 74 nouveaux-nés délivrés par extraction. Nous avons fixé arbitrairement le degré de gravité d'une extraction selon les trois groupes suivants:

1. **Extraction facile** jusqu'à 375 kpsec
2. **Extraction semi-difficile** de 376—1125 kpsec
3. **Extraction difficile** de 1126 kpsec et plus.

Il reste à déterminer si l'état dépressif néonatal résulte de l'extraction obstétricale ou d'autres causes. Les mesures du pH du sang artériel ombilical effectuées aussitôt post partum ont permis d'exclure chez au moins 4 des 11 cas de dépression l'hypoxémie comme cause de cet état dépressif, ce qui amène à suspecter une corrélation entre l'extraction obstétricale et l'état dépressif néonatal.

Nous estimons que cette méthode représente un progrès important pour compléter les données relatives à la naissance et éviter dans l'avenir des erreurs d'appréciation subjectives.

Mots-clés: Fetus, force de traction, ventouse.

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Prof. Dr. E. Saling
Unit of Perinatal Medicine
Mariendorfer Weg 28—38
D-1000 Berlin 44/Germany

Note: The complete equipment is manufactured and distributed by Knick, Katharinenstraße 2, D-1000 Berlin 37 (West-Berlin).